How Concurrent Engineering Reconfigures Process Engineering Activity - The Case of the Chemical Industry

Florence Charue-Duboc, Christophe Midler

CHAPTER 9

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The case of the chemical industry

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Beyond Project Management Radical Changes Within Department

The implementation of concurrent approaches in projects is of relevance to companies in a range of industrial sectors (Clark and Wheelwright, 1992, Midler, 1993, Eisenhardt and Tabrizi, 1995). But several authors refer to the difficulties encountered in its deployment: “US engineers tended to quickly decide ... trying to avoid ‘wasting resources’” (Sobek and Ward 1996); “managing these broad architectural iterations late in a project is not easy ... managers were unable to steer the investigation productively” (Iansiti 1995).

Of course such problems has been often called as the result of the conflict situations within matrix structures. But beyond these statements, what are precisely the implications of project development processes for the various departments involved ? How these department could adapt and renew their identity to facethe empowerment of project teams ? We will demonstrate in this chapter that the changes are rather radical and are then currently the stumbling block for more rapid dissemination of this project model, which is now fairly precisely defined. Our contribution will be to put forward an analytical framework identifying the various levels at which radical change occurs in departments contributing to design work.

We will illustrate this using an analysis of changes in process engineering in the chemical industry. This professional discipline, which forms a pivotal interface between upstream expertise (strategic marketing and research) and downstream players (manufacturers), has been particularly affected by the current changes. We will describe on three levels the features of the evolution initiated by the deployment of such projects. In the first section we describe the setting of the contributions of process engineers. In the second we focus on the content of their work. In the third part we deal with the implications for human resources management and the types of evaluation and contractualisation relationship existing between projects and departments.

The case studied here is that of Rhône-Poulenc, a major French chemicals group which has been undergoing strategic reorientation and a thoroughgoing review of its project management procedures since 1992. The data used have been built up in two ways. The first has involved the writing of monographs on recent projects (either now under way or just completed) based on semi-structured interviews with the main project players. Seven projects were examined in this way. The second is a real-time study of a project through attendance at committee meetings.

1. An Evolution of the Setting in which Engineering Take Part

During the 1980s, the chemicals company under consideration adopted project management methods on the conventional PMI model for the implementation of production plant construction projects, following a strategy directed at the development of production capacity and economies of scale. In the early 1990's the company changed its strategic direction. It began to withdraw from industrial chemicals markets and to turn toward the market for products offering high performance, high value-added and high innovation content, these being pharmaceuticals, agrochemical and specialist chemicals.

The projects coherent with this kind of business have specific characteristics. This was to lead to a modification of project management practices to match the characteristics of this type of projects, which combine areas of technical uncertainty with doubt as to commercial outlets. A concurrent project management model emerged and was gradually deployed throughout the group (Charue-Duboc 97). This new model has led to radical changes at four levels inthe contribution of engineering to projects.

The Overlap Paradox: Longer Involvement for Shorter Projects

The first change is a significant lengthening of the time-span of the project involvement of engineering departments. This is the direct consequence of three principles underlying the new models. Firstly, the development of anticipation: the formation of a multifunctional team must make it possible to raise issues of manufacturability early in the design of the product and to incorporate into the definition of the product the views of customers trying it. Next, maximum postponement of the moment at which highly irreversible choices are made (precise technical specifications, volume, etc.) in order to avoid being caught unprepared by rapid market evolution. Finally, ensuring overlap between the various project contributions so that the handover from design to production takes place in the best possible conditions and that all personnel involved are ready to react if problems arise at product launch.

A paradox affecting several project tasks is evident here for contributors such as engineering departments. In order to shorten overall development times, the engineering phase is lengthened. The engineers’ contribution begins earlier, at a point when the research work is not yet complete, and ends later, during plant start-up.

From a Stable Context to Flexible Work Situation

The second change to engineering work environment relates to uncertainty. The engineering is done at a time when numerous unknowns remain in the project. Conventional engineering organisation runs counter to this insofar as the work environment of each participant is clearly defined and contractualised at the outset when the project is broken down into distinct lots with associated detailed technical specifications.

From Sequential Processes to Interdependent Contributions

The third consequence is the interdependence of the contributions of the various participants. The goal of the new model is to find the best overall compromise by encouraging dialogue and mutual adjustments between project contributors. Their roles are not defined solely by the technical parameters of their respective disciplines, but also by the needs or constraints of the others, which will have determining importance for the collective outcome.

From Multiple Experts interventionsto Dedicated People to a Project

Finally, these novel approaches underscore the importance of continuity in project teams. The permanent presence of given individuals allows the formation of a project memory for decisions taken, directions chosen and ways forward looked at and abandoned. Such continuity is also a precondition for management founded on responsibility for results: the same players drawing up the projections will be responsible for achieving them.

Whereas engineering departments have reasoned up to now in terms of specialist workloads to meet a given need, they are now asked to assign individuals to take charge of all the issues related to a project throughout the duration of the engineering work.

2. Change in the Content of Work

These changes in the setting in which engineering department take part changein profound ways the actual activity of engineers. We deal below first with the impact of the overlapping of early project phases. We then go on to describe in detail the novel constraints stemming from the nesting of engineering and start-up planning.

From a Problem-Solving Approach to a Progressive Reduction of Uncertainty Balancing a Solution-driven Approach and the Analysis of Needs in a Limited Time-Span

In the sequential model, the process engineer uses detailed hypotheses provided by the project client (product specifications, volume, unit location, etc.) and research departments (defined process parameters and conditions). Using this data, gathered together under the heading of “base studies”, he goes on to specify the equipment (sizing, materials, etc.) and the operational parameters, grouped under the heading “detailed engineering”. The work of a process engineer is essentially of a problem-solving type (Simon 1969) and terminates once the installation has passed its acceptance inspection.

Under the concurrent scheme, the engineer begins his work, as we have seen, in a context which is considerably less clear and stable: the precise characteristics of the future product have not all been validated and a range of industrial scenarios and process constraints are not yet known. The work of the process engineer must then be built on and around such uncertainties.

His first step is to seek to define the areas of uncertainty and the status of the information handled by the project team. It is essential here to build up as soon as possible a common knowledge within the project on its principal areas of uncertainty and their potential impact. In order to isolate these, the process engineer begins to investigate and to test the proposals with the various players : research, marketing and strategy. It is in fact the latter who possess the information on the project components furthest from complete validation. It is they who can define the degree of confidence which the various hypotheses merit. Generally speaking, the documents given to engineering design personnel refer very little to such considerations. This task of exploring, qualifying and validating basic data is far removed from the work of process engineer in the sequential model, in which he usually feels that the status of the data given to him is not his concern: “if the hypotheses are wrong, that is not my problem but management’s”.

The second step is to select the small number of parameters for which the preservation of maximum room for manoeuvre is valuable, the others being frozen. A contribution from process engineering is also essential at this point. By building the scenarios for the various hypotheses, engineers can give the team as a whole a feel for what is at stake in the gradual freezing of project parameters. For example, if the optimum temperature range is not defined, engineering can make a distinction between different temperature ranges associated with various types of material and equipment and set out the costs and lead-times for each. These conclusions can then be compared and contrasted with those of the researchers, who have their own goals and choices, as shown in Table 1 below. Each team participant is the possessor of information on these two alternatives. Through his personal expertise, he has information on price and quality impact, in addition to evaluation criteria intrinsic to his professional discipline.

Table 1: A example of comparison between two development scenarios from different professional perspectives.

Strategies for action \ Project players	*Specify temperature without having all results*	*Do not specify temperature. Wait for further information.*
Research	Impact of a wrong decision: product quality, efficiency	Ability to deliver results by defined deadline
Project Manager	Financial impact on the project of poor production efficiency at this stage	Acceptability of uncertainty for investment
Customers	Acceptability of product at lower quality level	Ability to validate product by defined deadline.
Engineering	Extra capital outlay if temperature ends up having to be changed	Latest date by which this parameter must be specified. Extra cost involved in studies for several scenarios

The choice comes up by consolidating available knowledge and contrasting/-comparing evaluation criteria. Adler (1995) refers to joint team co-ordination. This means that a researcher's explorations may be halted because the consequences of delaying the freezing of the parameter in question would penalise the project too much. Or the equipment may be over-sized in order to retain the possibility of later process selection in the light of gains expected by researchers.

For the process engineer, the approach is no longer here one of "problem solving", in which answers are sought for clearly defined questions (questions and constraints give the solution), but one which is, in a sense, the opposite: accepting or rejecting constraints, freezing hypotheses or keeping options open in view of the consequences that such choices will have on subsequent development. This means that the problem is formulated in the light of anticipated possible solutions (hypothesis and solution A or hypotheses and solution B). This ability to formulate around a question a set of hypotheses, each with its own area of validity and implications, requires competence which goes beyond that required to answer a clear question. Schön (1983) highlights remarkably in his "conversation with the situation" metaphor that design activity cannot be reduced to "problem solving". Modern concurrent engineering approaches assign considerably more importance to the definition of problems and the building of working situations on constraint-based frameworks. Such methods therefore require even greater professional expertise in the relevant field.

The third step is to ensure the control of convergence on the parameters for which delayed specification has been chosen: milestones, control and vigilance. It is essential that process engineering should have responsibility to channel such convergence, given that it will have the task of assessing the required duration for the various sequential stages. It will also be process engineering's task to define the schedules by building back from the latest possible decision milestones, the dates at which design studies must be complete and item availability likely to influence choices. This department is therefore well placed to co-ordinate interactions within the project team by obtaining from the other players the information needed at a given date.

The description of design activity which we give above, on the basis of the analysis of the deployment of the concurrent model in a chemical company, has similarities with set-based design as conceptualised by Ward *et al.* (1995) using Toyota's design methods. The first step highlighted by us relates to the identification of areas of uncertainty and the small number of parameters which can effectively be considered to be fixed. The "impose minimum constraint" principle associated with set-based design fits this same logic. The second stage is to define hypothesis/solution pairings, starting out from the various solutions and reserving the option of late freezing of certain parameters. This procedure is similar to the following principles defined by Sobek and Ward (1996): definition of the feasible region, communication of sets of possibilities, exploration of tradeoffs by designing multiple alternatives, seeking a solution robust to the physical market and design variation, and smooth narrowing down of the sets. Finally, the last stage, the control of uncertainty, corresponds precisely to their "control by managing uncertainty at process gates".

How to Organise Engineering Activity with Downstream Rationale ?

We now come to the downstream part of the design process: the finalisation of engineering studies and their interfacing with the needs of plant operators. One of the first effects of the concurrent model for engineering is the systematic validation by downstream project players - plant operators - during the design work. The purpose of this is to reveal as soon as possible any problems which could otherwise arise in later phases. An example of this would be the inspection of installation scale models. The views of plant representatives are sought at this point in order to avoid demands arising at the final acceptance inspection stage. Modifications are obviously less costly (only the drawing needs to be redone) when problems are identified on a scale model, both financially and in terms of lost time, than if they are spotted when the unit has been built and the installations need to be physically altered.

For the design engineer, the aim is to bring out constraints stemming from operational management at a stage when their incorporation in the project will be less onerous. This leads to behaviour which, to some extent, goes against nature in that it involves going out to look for problems, and even to encourage their appearance. But beyond this, it involves understanding the needs of the plant and modifying project implementation to meet those needs.

A second consequence relates to planning logic. In the traditional model, the sequential unfolding of the various stages allowed each trade a high degree of planning autonomy within its own sphere, since its constraints were placed at its initial and final milestones. In the concurrent model, in which project schedules are nested, engineering, in planning its activities, is obliged to take account of logic totally foreign to its own preoccupations. An example of this is the planning of the construction and hand-over of the installations. The plant schedules acceptance inspections by line of piping, commencing with the utilities (i.e. air, water, etc.) and continuing by process step, with the objective of verifying compliance with process diagrams before sending in water and then product. Engineering plans plant construction and acceptance inspections by contract lot (electricity, piping, thermal lagging, etc.) and by supplier, since the need is to co-ordinate specialist contractors and to initiate payment once their respective tasks have been completed. We therefore have here two types of planning logic which are completely different, but equally relevant given the objectives of the two players.

Interfacing two sets of logic to accelerate the speed of start-up leads to extra and major constraints on construction planning. The task of the process engineer is to make enquiries to determine the priorities of the plant operators and their planning logic. He must then negotiate compromises since each player' preferences generally do not match spontaneously.

A third consequence of the implementation of the principles of concurrent engineering is that maximum advantage must be derived from each project stage to ensure maximum progress across the board. An example of this is the acceptance inspection phase. Its main purpose is to verify the compliance of the installations with the drawings, but it can also serve the purposes of operational training. It does in fact provide a marvellous opportunity to learn to operate installations in the field. Seizing the opportunity provided by acceptance inspections to further such skill acquisition enables this to be done earlier, saving time at start-up.

Such extraction of every possible advantage from each phase requires that each contributing trade must be highly transparent for the rest of the project. All players must be made aware of opportunities which can be exploited to good effect. For example, if the installations are not ready as planned for acceptance inspections, to what tasks can the teams be assigned? Conversely, if the teams are not ready for work, acceptance inspections will be delayed.

A fourth change relates to the ways in which the expertise of each discipline can be put to use for the project as a whole. Thus, players on the engineering side may be asked to contribute, on the basis of their skills, in activities which do not fit the standard profile of their professional tasks. For example, they may be asked to involve themselves personally in the training of the future operators of the plant, which enables direct transfer of expertise but is not always perceived as being part of the professional duties of engineers.

3. Toward New Organisational Artefacts for Knowledge Management and Staffing

These changes in the setting in which process engineers take part require a new look at the ways in which process engineering departments are organised both internally and in their relationship with projects

Skills and Careers Management

For many years now, engineering sectors have been subject to a powerful movement toward specialisation and standardisation of design activities. The outcome of this for design is a narrow compartmentalisation of skills and a formalism described by Mintzberg as "mechanistic bureaucracy" (1979), a model classically adopted in manufacturing industry. This type of organisation is obviously ill-suited to the new forms of activity described above, making it impossible to respond to the requirement of continuity in project contributions given the fragmentation of the expertise required between dozens of different players needed by several different projects. Furthermore, the implementation of standardised procedures is incompatible with the new activities involving exploration during the early project phases.

While it seems clear that this situation will see profound evolution, the alternative organisational models meeting the needs of concurrent engineering are considerably less evident.

Another typical configuration which could offer an interesting point of reference is “professional bureaucracy” (Mintzberg 1979). In this structure, which can be observed in hospitals and universities, the responsibilities and autonomy of the operational personnel (doctors, teachers, etc.) are much more highly developed than in the preceding model. Such a configuration is certainly better suited to certain requirements of concurrent engineering, particularly its ability to provide in-depth diagnostics and initiative, but it also possesses more problematic aspects which relate to the roles described above. These centre on three issues.

The first relates to the interfacing of the different fields of expertise. The definitions of these are undoubtedly less narrow than in the first configuration, but professional bureaucracy remains based in principle on a compartmentalisation of expert domains: the expert worker’s contribution stops at the boundary of his allotted field. That contribution presupposes initial “sorting” (a patient is steered towards a given department or different disciplines are balanced in drawing up a course of study) and the expert has little interest in integrating his contribution into a greater whole (e.g. the complete itinerary of a patient during hospital treatment (Minvielle 1996, or the student’s overall study programme). Assessment and evaluation of individuals are based on their field of action (peer judgement) and their careers are marked out within that same territory. In this type of system, the overall success of a project is determined by negotiation of interdisciplinary compromises and solidarity between different contributors is not promoted. One then observes the appearance in engineering departments of personnel management systems using several assessment and incentive schemes: for the short term a system of incentives encouraging involvement in projects (assessment of the experts by project management, bonuses linked to successful completion of key development milestones); for the medium term, career management building on the contributions made by the employee to the department (in addition to evaluation by the department head, career paths alternating between project and technical management posts).

The second relates to co-ordination with the other project players. In a professional bureaucracy, skills remain essentially unarticulated. Experts contribute on a basis of trust and lack of transparency, which is difficult to reconcile with the processes of negotiation and control of uncertainty described above. Given this fact, the most advanced management methods demand the explicit definition and formalisation of individual expertise. This is a difficult approach to implement since it is frequently perceived in this social context as a loss of trust and the imposition of management control over the expert.

Finally, capitalisation and transfer of skills. Learning processes in professional bureaucracies are based on processes of socialisation and tacit transfer of knowledge by long and poorly formalised interaction between "senior" and "junior" staff. This type of transmission is undermined by the fragmentation of the professional group between projects, as it is by the assignment of experts to immediate project objectives rather than to the transmission of their skills within their discipline. There is here a long-term risk for the very existence of the department if it cannot maintain its expertise and renew it to match on-going scientific and technological advances. But it also holds a risk for projects when chance and priorities result in the assignment of relatively inexperienced workers. The role of hierarchical structures is an essential one if the process of exchange and dialogue between experts is to be rebuilt and revived: the allocation to projects of pairings of part-time senior staff members and full-time junior staff, management of inter-project skill networks, and so on.

It can be seen that the search for answers to the problems raised by concurrent engineering for engineering departments demands the invention of new organisational configurations which are hybrids compared with the ideal forms described above. Over and above the difficulty of the development of new organisational schemes in itself, the management of the dynamics of the individual disciplines must take account of the vitality of models to which the institutionalisation of past years has given great coherence and legitimacy.

Resource Allocation Rules and Contracts Between Project and Department

In the company under consideration here, engineering departments are financed by a system of internal billing. Profit centres (or "Strategic Business Units") pay for services provided to projects according to a contractual scheme similar to that used for outside engineering firms. But do such financial relationships, based on the PMI contractual model for major civil engineering projects and the construction industry (Midler 1997), provide a good system of incentives for the adoption of the new professional practices involved in concurrent engineering?

As we have seen, the new methods owe their effectiveness particularly to anticipation and continuity of project contributions. This is reflected in a relative increase in the cost of engineering studies, which is theoretically more than offset by gains in net sales (reduction of lead-times to market) and the elimination of extra costs arising from system malfunctions (fewer project changes, reduction of losses during start-up), these being far less numerous and onerous than in the traditional sequential approach.

In the light of the above, the first risk arising from the conventional contractual approach is that it is too tightly focused on maximising the reduction in the initial projections of overall engineering costs. The engineering service provider responds by limiting his contribution. The outcome of this is a tendency to concentrate engineering contributions over as short a time-span as possible to enable staff to be reassigned to other projects, the purpose being to make maximum use of expert resources. This leads to a situation which runs counter to the principles of anticipation and project player continuity. Effective implementation of the concurrent model therefore presupposes that the billing-based approach is, in a sense, reversed: rather than starting out from “necessary” tasks and deducing from them the resources which are “indispensable”, the aim must be to define the resources to finance the retention of key expert personnel throughout the relevant period. The various financially viable tasks which can be given to the process engineer can then be sought, with a view to providing him with a workload spread over the entire duration of the project. This makes it possible to avoid reassigning him to another project between the end of the design phase and start-up.

Unless such thought is given to the boundaries of engineering’s contribution in concurrent projects, there is a major risk that projects will be subject to the ebb and flow of supply and demand in the engineering market. During periods of work overload, it will be very difficult to negotiate the retention of a contributor’s services throughout the duration of the project or his participation in activities judged to be marginal by his department (participation in training for example). Conversely, when the engineering department is under-employed, the project will be in a much better position in such negotiations, on condition that it can finance this continuity.

The other problematic aspect of the traditional contractual scheme relates to the initial formulation of project objectives. The contractual model lays down a straightforward division of responsibilities between the project client, who must set out in detail the targeted objective, and the project builders, who undertake to achieve that objective. A precise and detailed set of contractual specifications is the cornerstone of the economic relationship binding the parties.

This type of relationship acts as a brake on the implementation of the concurrent engineering model, in which, on the contrary, the aim is to fix as late as possible technical and operational features surrounded initially by considerable uncertainty. Traditional contractualisation in fact encourages engineering departments to avoid starting any design work until the contractual specifications have been finalised in every detail, and to bill heavily for any changes made thereafter. If, on the contrary, anticipation and interactive exploration of problems and possible solutions are to be encouraged, the need is to invent new contractual modes which incorporate the acquisition of project knowledge and the gradual freezing of the details of the contractual specifications. This type of system should offer financial encouragement to engineering departments to develop the design procedures described in the second part and it can also commit the project director, as project client, to clarification and acceptance of the risks associated with areas of uncertainty in the project. The reader is referred to Chapters 12of the present volume for novel approaches to contractualisation on the above lines.

While the literature on contracts is developing extensively at the present time, it remains focused on inter-company relationships. It can be seen that similar issues relating to internal billing arise within companies. Contractual structures designed to underpin alliances between companies can also provide a starting point for the adaptation of internal contracts.

The 1990s are witnessto a revolution in design organisation as radical and wide-ranging as that experienced by production departments in the 1980s. The first phase of that revolution essentially affected the co-ordination of the various disciplines contributing to projects and the role which embodied such co-ordination: that of the project manager. Today, a second phase has begun which involves a thorough review of the various departments involved in product design. We have seen in this chapter, with the example of process engineering, that such a review extends from individual practice through to overall departmental organisation and financial relationships with projects. Similar observations could be made for other professional domains such as research and marketingdeveloped in the following chapters.